A CASE STUDY

OF IN SITU STABILIZATION OF METALS AND RADIONUCLIDES

The primer concludes here with a case study of a hypothetical site. This study illustrates one type of contaminant problem occurring on DOE lands and presents a methodology that can be used to stabilize some of the more mobile contaminants on this site. The hypothetical site is representative of U.S. Department of Energy sites contaminated with complex mixtures of metals and radionuclides.

SCOPE OF PROBLEM

Contaminants Present: A complex contaminant mixture of uranium (U), chromium (Cr), and technetium (Tc) has entered an unconfined aquifer (an aquifer connected to the surface) as a result of nuclear fuel reprocessing and other operations at the site. Underlying a vadose zone of 10 meters from the ground surface (Figure 6.1), the aquifer is approximately 5 meters thick and consists of sandy gravels interspersed with sediments containing silts and clays. The contaminant plume, migrating at a rate of 0.3 meters per day, contains sufficient U, Cr, and Tc to be of regulatory concern. It also discharges to a river that constitutes an aquatic resource and drinking water supply. The water is aerobic (8–10 ppm oxygen), and the contam-

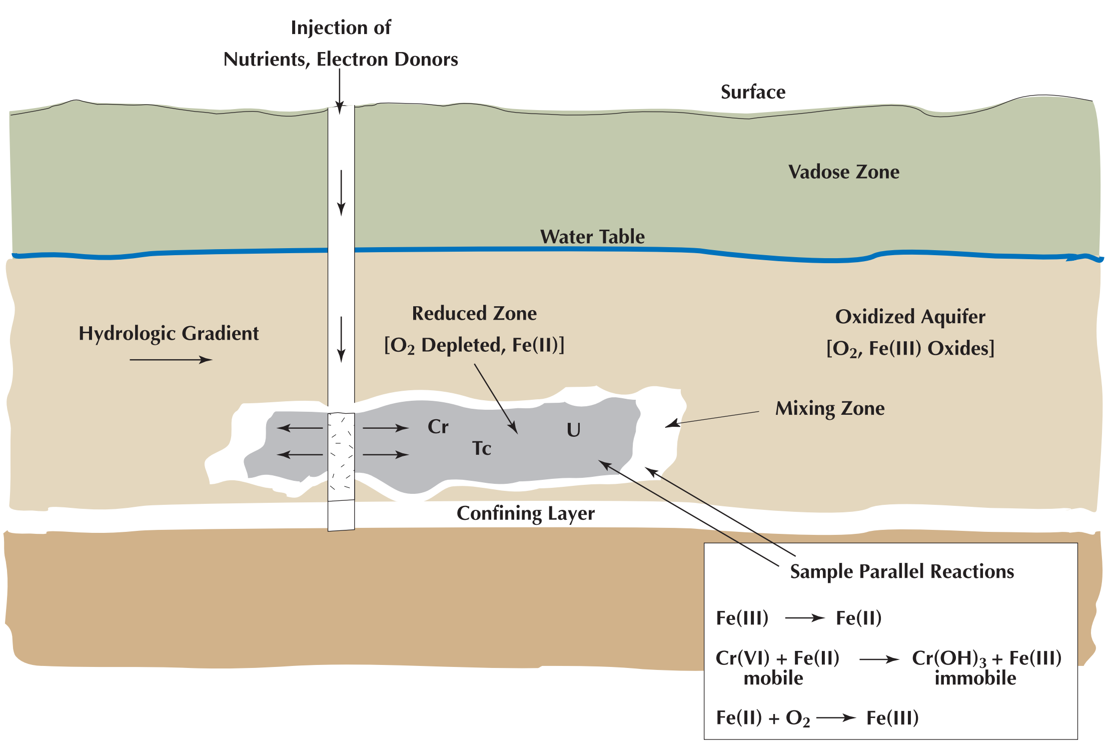

Figure 6.1. In situ stabilization of metals through accelerated bioremediation.

inants are present in oxidized states as U(VI), Cr(VI), and Tc(VII). The plume is 80 meters in width, and the site thus qualifies for immediate remedial action to protect the river.

Present Technology: The baseline technology for groundwater at the hypothetical site has been pump and treat, followed by disposal or reinjection of treated water. This process can be costly and inefficient because of difficulties in removing all of the contaminated water and contaminants sorbed on mineral surfaces. Removal and aboveground treatment of radioactive waste are also very hazardous. In addition, pump and treat can take decades and disposal of the contamination removed from the groundwater will still be necessary.

METHODOLOGY

The Alternative: Create a permeable treatment zone in the aquifer that removes the metals and radionuclides from the groundwater before they impinge on sensitive water supplies. If the groundwater is below approximately 15 meters, the treatment zone must take advantage of in situ processes, as it becomes impractical to excavate and place barrier materials below these depths.

A Role for In Situ Bioremediation: Unconfined aquifers are often oxidizing environments in which elements such as U, Cr, and Tc are mobile in their oxidized forms. Yet, microorganisms that normally operate in the absence of oxygen may occupy niches in these environments. They may also be encouraged to alter the form of these elements so that they are retained on minerals within the sediments and removed from the groundwater.

For example, a group of microorganisms known as iron reducers are able to conserve energy for growth and reproduction by converting oxidized iron [Fe(III)] to reduced iron [Fe(II)]. These organisms could directly immobilize metals and radionuclides and enzymatically convert them to chemically reduced states. The contaminants then would become associated with sediments and therefore would also become less mobile in groundwater. Or, iron reducers may indirectly immobilize these contaminants through the reduction of Fe(III) in mineral structures to Fe(II). This, in turn, chemically reduces the metals to less mobile forms. The indirect method is probably the most desirable for in situ technologies because it produces a relatively stable reactive solid phase that may exist for many years in groundwater environments, forming a long-lasting permeable barrier to further transport of the contaminants.

The Challenges: Taking advantage of native populations of microorganisms for in situ treatments to remove metals and radionuclides from groundwater is very challenging. Obstacles must be overcome by innovative science and engineering, making use of the disciplines of microbiology, geochemistry, hydrology, and geophysics. However, the potential benefits are immense because use of indigenous microorganisms may eliminate the need for pumping and treating, particularly in situations that require immediate action.

IMPLEMENTATION AND MONITORING STEPS

1. **Facilitate the growth of iron-reducing organisms:** This might be accomplished by supplying readily available organic carbon to native heterotrophic microorganisms that use up oxygen in the water, thereby supplying electron donors. Bioaugmentation could also be put into play by concentrating native organisms from the groundwater and reinoculating them into groundwater at the subsurface barrier location.

2. **Estimate biotic reduction of subsurface minerals:** This will require an understanding of the mineralogy of the subsurface and the effect of iron-reducing microorganisms on surface iron and structural iron.[1] When surface iron is reduced to Fe(II) it will be re-adsorbed into the treatment zone or the oxidized zones downgradient from the treatment zone. (In this scenario, structural iron will serve as the primary long-term reducing agent.) This step will also require an understanding of the interactions of the oxidized contaminants with biologically reduced minerals and the ability to predict the duration of immobilization under groundwater conditions.

3. **Deliver microorganisms, carbon sources, and electron donors:** Major challenges exist in creating an in situ treatment at a specific location in the subsurface, which can only be visible remotely through the narrow window of observation offered by drilling. Detailed hydrologic models coupled with geophysical, geochemical, and biological process-level information and models must be used in an integrated way to establish treatment conditions in time and space.

4. **Monitor and evaluate results:** Challenges similar to those that exist in design and implementation of the treatment process also occur in evaluating the results of treatment. The long-term effectiveness of the treatment and potential impact on natural microbial communities must be determined. Key questions that must be answered include: How effective was reduced iron in removing the contaminants? When will structural iron be completely utilized and retreatment needed? What is the likelihood that a pulse of contaminant will be released from the barrier as the system reoxidizes?

REWARDS

The fundamental knowledge needed to use biological processes for in situ treatment of metals and radionuclides and predicting the effects on groundwater systems is formidable. However, the ability to effectively stabilize contaminant movement in the subsurface with a minimum use of energy and chemicals offers a new and perhaps cost-efficient tool for situations where the existing baseline technology is not acceptable.

1. Structural iron is associated with the crystalline mineral. Amorphous iron forms a coating over the mineral. Because structural iron is an integral part of the mineral itself, it serves better as a long-term reducing agent than amorphous iron, which may be dissolved and eventually lost in the groundwater.